ASSESSMENT OF BUILDING ENERGY PERFORMANCE FOR ENERGY EFFICIENCY MEASURES IN SELECTED COMMERCIAL BUILDINGS OF INDIA

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SYNOPSIS

SUBMITTED TO

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By

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Certificate

*This is to certify that the synopsis entitled "**Assessment of Building Energy Performance for Energy Efficiency Measures in Selected Commercial Buildings of India**" submitted by **Mr. Tej Singh Chouhan** (Registration No. 4410070) to JJT University, Jhunjhunu in the partial fulfillment of the requirement for the award of degree of **'Doctor of Philosophy' in Mechanical Engineering** is a bona fide record of the research work carried out by him under my supervision and guidance. The synopsis has been completed to the best of my satisfaction. To the best of my knowledge, it is an original work and matter embodied in this synopsis have not been submitted to any other Institute or University for the award of any other degree. The synopsis is upto the standard both in respect of content and language for being referred.*

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SYNOPSIS

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Introduction

The systematic way to measure and analyze the building energy performance has been one of the key interests of building designers in past decade. Although efforts have been made in this area, building energy performance remains a mystery to many of them. Energy use in buildings at present is ill-conceived and not well understood because the parameters involved are complex, diverse and insubstantial in nature. To tackle this difficulty, computer simulation models have been developed to help the building designers and energy analysts in conducting detailed building energy analysis. These models have been accepted as the most powerful and flexible tools for investigating building energy performance, and has been used extensively in the world for supporting the development of modern building energy standards.[1,2,3]

Despite of the growing implications for computer building energy simulation, yet application of the simulation tools and techniques are problematic. There is a gap between the technology as applied by using computer and what is being adopted and understood by the practicing building designers.

With a growing concern regarding energy efficiency, developing countries have begun to investigate and develop their own building energy standards. But the tasks are often being hindered by the breadth of the subject and the complexity of building energy analysis.[4] In most countries by reducing the energy demand, excessive dependence on imported fuels can be minimized. Indian Government has initiated control measures by stimulating energy efficiency improvements and the formulation of building energy standards. Economic and environmental factors are also causing the prospective building owners and developers to be progressively more concerned with energy costs and also to transmit this concern to the commercial building designers through a demand for more energy-efficient buildings.

Commercial buildings are becoming major consumers of electrical energy because of their continuous operation of HAVC system to maintain indoor thermal comfort.

[1] (Deringer & Busch, 1992)
[2] (Wilcox, 1991)
[3] (SRC Australia Pry Ltd, 1993)
[4] (Hui & Lam, 1991)

Growing importance of energy conservation and energy management have resulted in energy efficient systems, most of which compromise with the indoor thermal quality and lighting. Some of the most common techniques adopted globally for energy efficiency are the reduction in the control of temperature, ventilation rate and humidity that may result in unsatisfactory indoor thermal environment. This attitude of designer should be rectified as poor indoor conditions which can lead to lower productivity and rise in health-care cost. Therefore there is a pressing need to investigate the impact of energy efficiency measures on HVAC system operation for energy consumption relative to thermal comfort being achieved. Impact of energy efficiency measures on HVAC system operation with the help of energy simulation tools in commercial buildings of India is not known so far and needs to be identified.

Buildings are responsible for at least 40% of energy use in most countries. The absolute figure is rising very fast, as construction is booming, especially in countries such as China and India. It is essential to act now, because buildings can make a major contribution in tackling climatic change and energy consumption. The construction sector in India is witnessing a fast growth. The gross built-up area added to commercial and residential spaces was about 40.8 million square meters in 2004/05, which is about 1% of annual average constructed floor area around the world, and the trend shows a sustained growth of 10% over the coming years. With a near consistent 8% rise in annual energy consumption in the residential and commercial sectors, energy consumption in buildings has seen an increase from a low of 14% in the 1970s to nearly 33% in 2004/05. This is directly related to higher greenhouse gas emissions, which can be countered by constructing high performance energy-efficient buildings.[5]

The steady increase in energy consumption and demand will eventually require further investment in energy generation; otherwise serious shortage may occur. In most countries including India, building sector consumes major portion of the electrical energy generated. Industrial and commercial buildings consume significant part of energy, yet possess great potential for energy savings due to their operational characteristics. In many areas of India presence of harsh climatic conditions

[5] (Kumar, 2010)

necessitates air conditioners. The HVAC system alone consumes 65% of the total energy delivered to the commercial buildings; hence identification and implementation of appropriate energy efficiency measures can significantly reduce energy consumption. Energy efficiency measures are generally the least expensive means of reducing energy consumption and thereby ameliorating adverse environmental impacts. It can be thought that bringing the tools for energy conservation under one roof will be useful for engineers in designing and building energy-efficient systems for commercial applications.

The results of the simulation shall show that the significant efficiency improvement can reduce total building annual energy use resulting in annual running cost savings. The study shall also show that sufficient "low hanging fruit" type energy efficiency potential exists in the existing building stock to be a significant contributor towards a more sustainable future. The study will give the appropriate energy efficiency measures for building envelop, HVAC system and lighting system to obtain thermal comfort and required light power density at reduced energy consumption for commercial buildings of India. The successful implementation of energy efficiency measures will lead to reduce the overall cost of energy consumption up to expected level which will lead to greener economy by conservation of energy.

Literature Review

To meet the world growing energy service needs, improving electricity end-use efficiency is very essential. The potential for electricity savings is probably greatest in commercial buildings where a significant portion of the energy demand is expended by heating, ventilating and air conditioning (HVAC) and lighting systems.[6] A number of technologies and opportunities such as energy efficient buildings and lighting system have been identified and studied in developed countries[7,8], but their applicability and effectiveness in developing countries, like India, are seldom evaluated extensively. There is a quest for long-term energy policy and systematic measures for achieving energy efficiency. The measures designed for buildings usually aim at improving

[6] (Bevington & Rosenfeld, 1990)
[7] (Holtz, 1990)
[8] (Morse, 1990)

present techniques, making the best use of unexploited research results, developing new technologies and approaches for practical use.[9] It is believed that more efficient building energy utilization is attainable and energy optimization is conceivable by using the present-day techniques effectively in building design and operation. *Majali, V. et al.* presented the development and applications of computer aided building energy simulation. Important features of some popular building simulation software were mentioned. In view of this and the rapid advancement in computer technology, some of the possible research and development trends in building design and simulation were mentioned in their study.[10] According to *Urban, Bryan J.* simulation tools, when applied early in the design process, can considerably reduce the energy demand of newly constructed buildings. In this document the "MIT Design Advisor" has presented as a simple and rapid building energy simulation tool, developed specifically for architects and building designers. Conceptual building designs can be modeled quickly and without formal training. The heat transfer model used to make the energy predictions has been explained in this study.[11]

Energy and indoor environmental audits of energy consumption and indoor air quality were taken in 24 school buildings in Slovenia by *Butala and Novak*. The audits show that these buildings were high energy consumers and have poor indoor air quality, as expressed by 60% of the surveyed respondents. This article deals with energy consumption in the analysed schools. The heat losses of the school buildings were 89% higher than the recommended values. According to their analysis of the possible measures to improve the situation in the school buildings, it was not possible to ensure rational energy use and good indoor air quality with low investment costs.[12] *Franken,* studied the green building at Duke University, potential energy savings and GHG benefits achieved by renovating existing residence halls. This study assessed the energy and environmental benefits achieved through a LEED-certified renovation at Duke University's Kilgo Quad. This renovation was expected to provide 32% better energy efficiency and 20% to 30% better water efficiency than the industry standard design building, while upgrading mechanical systems and electrical wiring and adding central air conditioning for the first time. The audit results were then compared to a

[9] (International Energy Agency, 1990)
[10] (Majali, Dr. Prasad, & Dr. Bhat, 2005)
[11] (Urban, 2007)
[12] (Butala & Novak, 1999)

baseline measured at Few Quad, which was slated for a similar renovation in summer 2008, to gauge relative performance before and after the Kilgo renovation.[13] According to the study of *Dimoudi and Kostarela* energy efficiency is very important in school buildings as it is associated with comfort and air quality conditions in their interior and energy costs of these buildings were associated with their main operational costs. The aim of this study was to assess the energy performance, based on monitored data, of school buildings in the C climatic zone of Greece, a region with the lowest air temperature during winter period. It was also demonstrated, through simulation studies, the potential for energy conservation of school buildings in this region.[14] According to the author *Sam C.M. Hui*, Building energy simulation is important for the study of energy efficiency in buildings. This study has explained the basic concept of energy simulation in building design and the properties of simulation design tools. Efficient simulation practice has been discussed in the context of integrated building design systems. This research discussed some of the research in building energy simulation techniques in Hong Kong.[15]

Drury B. Crawley et al. contrasted the capabilities of building energy performance simulation programs and have been given an overview of a report which provides up-to-date comparison of the features and capabilities of twenty major building energy simulation programs. The comparison was based on information provided by the program developers in the following categories: general modeling features; zone loads; building envelope and day lighting and solar; infiltration, ventilation and multizone airflow; renewable energy systems; electrical systems and equipment; HVAC systems; HVAC equipment; environmental emissions; economic evaluation; climate data availability, results reporting; validation; and user interface, links to other programs, and availability.[16] *Erhorn et al.* has given the Energy Concept Adviser i.e. a tool to improve energy efficiency in educational buildings. The study displayed many similar design, operation and maintenance features in most countries for educational buildings such as kindergartens, schools and universities. However, studies have shown that during retrofit, energy saving measures were rarely applied, because the decision-makers lack knowledge of investments and the efficiency of potential energy

[13] (Franken, 2008)
[14] (Dimoudi & Kostarela, 2009)
[15] (Hui S. C., 1998)
[16] (Crawley, Hand, Kummert, & Griffith, 2005)

saving measures. This paper describes a tool that assists educational building decision-makers while the construction project is still in the design phase. The ECA includes suggestions of energy systems to use and potential design concepts to be considered during the design phase.[17] *Qingmiao Han et al.* elaborated the commercial patterns of China existing building energy retrofit based on energy management contract. Their study of existing building energy retrofit is one of the key in building energy efficiency in China. Their study presented the specialties and difficulties of existing building energy conservation in China and the development, service items and commercial patterns of EMC. Based on the analysis of three commercial patterns of EMC including guaranteed savings contract, shared savings contract and chauffage contract, researchers proposed that the guaranteed savings contract was the main development direction of building energy efficiency service in China.[18]

According to the study of *Iqbal, I and Al-Homoud M.S.* the growth of demand for electrical energy in the rapidly expanding towns, cities and industries exceeds the growth of the power being made available. Therefore, energy conservation has become an increasingly important issue in Saudi buildings. The objective of this study was to investigate the impact of alternative energy conservation measures on energy requirements in office buildings in hot-humid climates. The study was conducted on a five-story office building located in Dammam, Saudi Arabia, which was in use since 1998. Different types of HVAC systems were selected and different feasible and practical operational energy conservation measures were evaluated using the energy simulation software of Visual DOE 4.0.[19] In the assessment of buildings thermal indoor climate in Netherlands, the directives used were the ones given in 1979 and 1991 by the Government Buildings Agency (GBA). The criteria formulated in 1991 in the form of 'weighted excess hours' were a subject for debate. This article treated these directives and their backgrounds. Additionally, it contained information about a project started in September 2000 with as a goal to innovate these directives. This project was developed with the support of NOVEM and the GBA. On the one hand, it tried to improve and optimise the communication necessary with regards to the

[17] (Erhorn, Mroz, Mørck, Schmidt, Schoff, & Thomsen, 2008)
[18] (Han, Sun, & Liu, 2006)
[19] (Iqbal & Al-Homoud, 2006)

debates on backgrounds.[20]

Impact of the natural ventilation on the building depends on the design of the several components of the building like facade, HVAC and control system. Paper presented several tests of the building with different selection of the components. The double skin facade was compared to the single skin facade with the external or internal shading device and with climate wall. Furthermore, impact of the mechanical or natural night cooling, predictive control was discussed. Final solution represented the possible reduction in HVAC system to balance the costs of the double skin facade. The tests were carried out with the simulation program built in Simulink™ validated with the measurements taken in Test cell at TU Delft as well as in the real office building.[21] *Sutter et al.* registered how eight subjects used their remotely controlled black Venetian blinds in eight individual offices, every 15 min, over a period of 30 weeks. This also included measuring parameters such as the illuminance on the window, the illuminance on the VDU screen, the ambient temperature inside the room, the presence of the worker and the state of the artificial lighting. With the data collected, several hypotheses regarding the use of Venetian blinds in offices were tested. They came to the conclusion that the higher the quality of the VDU screen (in terms of emitted luminance levels), the more likely a worker was to tolerate high levels of diffuse reflections on it, hence taking more advantage of the daylight available.[22]

The paper "Use of energy performance simulation for operation cost distribution in multipurpose conventional centre" has described a case study for application of computer simulation in the field of operational energy costs distribution in the building with variable operation and no possibility of direct energy consumption measuring. The simulation was used to predict energy needs related to the climatic loads and to make a synergy with the internal loads. Presented results were in terms of average energy consumption related to floor area and operational case, divided into the heating, cooling and electric energy. This method could be used for distribution of the operational energy costs in the buildings, where there is no possibility of

[20] (Linden, Boerstra, Raue, & Kurvers, 2002)
[21] (Stec & Paassen, 2005)
[22] (Sutter, Dumortier, & Fontoynont, 2006)

measuring of the primary energies and which are known as the operational schedules of heat gains and usage of the building.[23] *Cheung and Hui* in their paper briefly introduced the basic principles of building energy simulation, explained its relationship with air-conditioning load and energy calculations, and described the application in air-conditioning design. Simulation methods can provide analytical power for the study and improvement of building performance.[24]

The study concerned energy performance and building classification in compliance with the standards for non mandatory labeling of commercial, services and public building efficiency level developed to comply with the law, regarding minimum energy efficiency levels in Brazil. The objectives were the classification of the concerned buildings; the study of electrical systems improvement and building envelope proposals, generally and specifically in the case study, to reduce the electrical energy consumption; the emission of CO_2 relative to energy consumption; the added cost due to the improvement proposals; and the evaluation of cost-benefit related to the measures that reduce the electrical energy consumption.[25] Electricity generation in Jordan has been among the largest sectors of energy consumption of primary energy. The electricity audit at hand was a case study with the objective of identifying the major areas of electricity consumption of the different income groups of the population of Amman. The approach used in the case study can also be useful to other developing countries. The major consumption areas of electricity in Amman were conditioning (26%), food reservation (19.1%), illumination (19%) and water heating (13.1%). Utilization of hybrid systems that consist of solar and wind energy can reduce the electricity bill with respect to water heating, conditioning and food reservation.[26] Another paper presented a model of a commercial building in Shanghai with energy simulation software, and after calibration, the energy consumption of this building was calculated. On the basis of the simulation and calculation, a series of energy saving measures are suggested and their effects are evaluated. The paper verifies the application of computer simulation in building energy analysis and energy saving evaluation.[27]

[23] (Kabele, Centnerova, & Krtkova, 2001)
[24] (Cheung & Hui, 1998)
[25] (Batista & Rovere, 2009)
[26] (Kablan, Alhusein, & Alkhamis, 1999)
[27] (Chen, Pan, Huang, & Wu, 2006)

The aim of the study was to develop a simple model to predict the electric energy consumption of office buildings artificially air-conditioned, for fourteen Brazilian cities. Many variables were tested to seek those more important to be used to predict the electricity consumption. The variables that have been selected were the size of the building (number of floors and the shape size), the façade composition (window to wall ratio), thermal transmittance and absorptance of roof, the shading coefficient of gazing, the solar protection, façade and roof colours, occupants and electric power density (lights and equipments). The equations demonstrated good results with r^2 higher than 0.99 for most cities.[28] A study of "whole building energy simulation with complex external shading devices" has been shown as an approach for pre-calculating building façade incident irradiance levels under a typical, yet computationally complex, external shading device with state-of-the-art ray tracing simulation techniques were presented. The impact of accurate modeling of direct solar, diffuse sky and inter-reflected irradiance components on resulting levels of thermal comfort and energy demand was analysed and recommendations were given for improvement of modeling capabilities.[29] A comparison study of energy consumptions of different building heating systems for various meteorological regions of Iran illustrated how to simulate heating systems in buildings, a research oriented computer code was developed in Sharif University of Technology in Iran where the climate, existing heating equipment in buildings, consumer behavior and their interactions were considered for simulating energy consumption in conventional systems such as heaters, radiators and fan-coils. The study has shown that by changing heater to radiator rendered energy conservation up to 50% in all climates and by changing radiator to fan-coil decreased energy consumption in climates with cold and dry winter.[30]

The existing buildings stock in European countries accounted for over 40% of final energy consumption in the European Union (EU) member states, of which residential use represented 63% of total energy consumption in the buildings sector. This paper presented an overview of the method and software that can be used to perform building energy audits and assessed buildings in a uniform way, perform demand and

[28] (Signor, Westphal, & Lamberts, 2001)
[29] (Janák, 2003)
[30] (Hannani, Azimi, & Nikoofard, 2008)

savings calculations, provide owners with specific advice for measures to improve energy performance, issue an energy performance certificate for existing buildings, and include some representative results from the pilot studies performed in several European countries.[31] The authors reviewed the work on energy efficiency in Hong Kong and discussed the prescriptive and performance-based approaches as well as looking at the obstacles and barriers in delivering energy efficiency to the marketplace. It is recognised that more research and development work needs to be done in the territory before comprehensive building energy codes can be introduced. Compared with some of its Asian neighbors, Hong Kong was the newcomer in the development of building energy standards.[32]

Measuring or estimating thermal properties of anisotropic building materials can be the key for obtaining the optimum performance for a particular application. The intensive researches on development of new building materials have necessitated in situ thermal testing apparatus in most research laboratories. Only few standardised techniques were available for accurate thermal testing of anisotropic materials, and they were generally expensive. Sample measurements with ordinary concrete and rubberized concretes were performed. The effective thermal transmittances of rubberized concretes were found to be considerably lower than that of the ordinary one.[33]

It has been widely recognised that making significant reductions in carbon emissions from the building sector require considerable improvement to the energy efficiency of the existing stock. Both the UK government in its White Paper on energy policy (DTI, 2003) and the European Union (EU Directive, EU 2002) stress the importance of building regulation in helping to bring about the improvements required. Technological solutions were available and well understood but they were often not applied. This paper reviewed existing regulatory provision and discussed ways in which it could be modified or new mechanisms can be developed so as to have a greater impact on the performance of existing buildings.[34] Indoor thermal environments and residents which control behavior of cooling and heating systems

[31] (Poel, Cruchten, & Balaras, 2007)
[32] (Lam & Hui, 1996)
[33] (Yesilata & Turgut, 2007)
[34] (Bell, 2004)

were investigated in Seoul, Korea and compared with the results of previous studies. Twenty four houses in summer, six houses in autumn and 36 houses in winter were used in this study. The measurement of temperature, humidity and air conditioner usage behavior was carried out. This result indicated that the development of an HVAC system has created an expectation of comfort for residents and has shifted their thermal comfort zone warmer in winter and cooler in summer.[35] A simplified building HVAC system model was presented by Bertagnolio et al. It has included simplified models of building zones and of HVAC equipment. The simplified building zone model on a R and C network, whose parameters were adjusted through a frequency characteristic analysis. The simplified building model was compared with more detailed models, using the BESTEST procedure. The application of the presented model to the audit of commercial buildings was also discussed.[36]

The paper summarizes a research project that was under completion at Delft University of Technology, Faculty of Architecture, and Building Physics Group. The general problem addressed in this project was the integration of building simulation tools and building design. The main goal of the research presented in this paper was the development of a strategy to provide computational support during the building design process for rational design decisions regarding the selection of energy saving building components, has to be achieved. The elements of the strategy have been described; a prototype support environment has shown how the strategy can be harnessed in a support environment that supports interaction between building design and building simulation.[37]

The annual power consumption of a five-star hotel was analysed with computer simulation, followed by full scale experiment for validation. Comparative result indicated that significant energy savings, up to 15.4 % annually, can be expected in this high-rise building if the chiller plant, especially the chilled water distribution system can be renovated with variable speed driven pumps. The potential savings could be up to 15.4% annually when more energy efficient measures were brought into the existing chiller plant. The successful implementation of this evaluation process on the LD hotel, both analytically and experimentally, has warranted its

[35] (Bae & Chun, 2009)
[36] (Bertagnolio, Masy, Lebrun, & André, 2008)
[37] (Wilde & Voorden, 2003)

application in other engineering projects.[38] *Holmes & Hacker* addressed the dual challenge of designing sustainable low-energy buildings while still providing thermal comfort under warmer summer conditions. The main focus was towards buildings that were 'free running' for some part of the summer, either being entirely naturally ventilated or mixed-mode (where mechanical cooling was only used when thought to be essential). Because the climate is changing and outside summer temperatures are expected to increase, the future will offer greater challenges to the designers of sustainable buildings aiming to provide either entirely passive or low-energy comfort cooling. These issues were demonstrated by predictions of the performance of some case study buildings under a climate change scenario. The examples also demonstrated some of the important principles associated with climate sensitive low energy design.[39]

Investigating thermal comfort conditions in outdoor urban spaces, has thrown some light on the complexity of the issues involved, demonstrating that a quantitative approach was insufficient in describing comfort conditions outdoors. This paper concentrated on the issue of psychological adaptation: naturalness, expectations, experience (short-/long-term), time of exposure, perceived control and environmental stimulation, and presented an attempt to try and evaluate the relative impact of each of these parameters.[40]

Energy consumption in buildings is currently a real problem. That is why both assessment of energy performance and effective energy management are essential. In this context, the study focused on developing a commercial monitoring station (BEMS) with the support of three industrial partners, Apex-BP Solar, Pyrescom and the "Centre Scientifique et Technique du Bâtiment" (CSTB). This device was designed for (*i*) on-line monitoring environmental and energetic parameters, (*ii*) on-line computing a global energy indicator, (*iii*) estimating the renewable energy resource of the location and (*iv*) advanced heating control.[41]

[38] (Yang & Wu, 2003)
[39] (Holmes & Hacker, 2007)
[40] (Nikolopoulou & Steemers, 2003)
[41] (Paris, Talbert, Eynard, Grieu, Traoré, & Polit, 2009)

The study addressed uncertainties in building performance evaluations and their potential impact on design decisions. Design evolution involves a chain of design decisions. Each decision was supported by input supplied by the various domain experts to the design team at large. The research has focused on the domain expertise of the building physics expert, responsible for those inputs that sustain rational decisions with respect to energy use, thermal comfort, HVAC system sizing etc. Prime attention has been given to thermal comfort.[42]

The U.S. Departments of Energy and Defense (DOE and DOD) has jointly developed Energy Base, a new building energy simulation tool that was builded on the capabilities of BLAST and DOE-2. Energy Base included innovative simulation features, including variable time steps, built-in template and external modular systems simulation modules integrated with a heat balance-based zone simulation, and input and output data structures tailored to facilitate third party interface development. The study has described the methods used and given a brief overview of the organisation and anticipated capabilities of Energy Base.[43]

Energy simulation models were developed with EnergyPlus for two office buildings in a R&D center in Shanghai, China to evaluate the energy cost savings of green building design options compared with the baseline building. As a R&D center of an international IT corporation, there were data centers in the two buildings, which make them different from typical office buildings. The whole building energy simulation results has shown that the yearly energy cost saving of the proposed design was proposed to be approximately 27% from China code building and 21% from ASHRAE budget building, which was 4 points for LEED credit due to energy performance optimization.[44]

Many of the popular building energy simulation programs around the world were reaching maturity - some used simulation methods (and even code) that originated in the 1960s. For more than two decades, the U. S. government supported development of two hourly building energy simulation programs, BLAST and DOE–2. Designed in

[42] (Wit & Augenbroe, 2001)
[43] (Crawley, et al., 1997)
[44] (Pan, Yin, & Huang, 2008)

the days of mainframe computers, expanding their capabilities further has become difficult, time-consuming, and expensive. Because of these problems, a U.S. federal agency began developing a new building energy simulation tool, EnergyPlus, building on the capabilities and features of BLAST and DOE-2. This paper focused on the structure, features, and capabilities of EnergyPlus.[45]

Objective

The overall objective of this project is to demonstrate how a holistic approach in refurbishment of proposed commercial buildings and the commercial building under design phase can provide energy efficient system with the inclusion of modeling, simulation and the extension of energy efficiency measures. The main objectives of this study are as follows:

1. To investigate the impacts of building envelop, HVAC and lighting design parameters on energy efficiency in selected commercial buildings of India.
2. To identify energy efficiency measures in building envelop, HVAC and lighting system for energy conservation in the selected commercial buildings of India.
3. To compare the impact of identified energy efficiency measures on building energy performance among the selected commercial buildings.
4. To perform cost benefit analysis on identified energy efficiency measures.
5. To recommend appropriate energy efficiency measures and develop guidelines for commercial buildings in India based on energy simulation results to achieve potential lower energy consumption per square feet area without compromising thermal comfort.

Hypothesis

The study will elaborate the energy efficiency measures. Researcher seeks to recommend energy efficiency measures to implement for energy conservation. The study leads to recommendations for quantifiable energy savings in commercial

[45] (Crawley, et al., 1999)

buildings of India by applying appropriate energy efficiency measures along with some strategies of HVAC and lighting system which leads energy saving without compromising in thermal comfort.

The recommended energy efficiency measures and guidelines can be included in building energy conservation codes for commercial buildings in India. If these energy efficiency measures are made mandatory for all new upcoming commercial buildings of India having conditioned area between one lakh to six lakh square feet or above, It will lead to huge energy cost saving and conservation of energy. The expected energy savings shall be between 15% to 28% and estimated energy cost savings shall be 17% to 30% with payback on investment within 1 to 6 years.

Methodology

The researcher seeks to throw light on energy efficiency measures in commercial buildings of India through a systematic assessment of building energy performance. Building HVAC and lighting system operation strategies for energy conservation with the help of energy simulation using eQUEST-3.63b software will be used to find appropriate energy efficiency measures to improve energy efficiency of commercial buildings. For this study proposed commercial buildings which are under design phase, located in India shall be selected to identify their building energy and thermal performance. To achieve this goal, data regarding building envelope parameters such as glass, wall, roof, building HVAC and lighting design parameters, building operating schedule etc shall be collected for at least eight to ten commercial buildings situated in India. Researcher shall exhibit certain logical tools such as energy efficiency measures which will prove to be extremely effective in selecting the prime candidates for an energy efficiency improvement effort. Energy engineering efforts such as detailed energy modeling can be extremely valuable strategies for identifying energy efficiency opportunities in both existing and new commercial buildings and can go a long way towards a greener building and a greener future. Building simulation shall be done in eQUEST-3.63b software which is a building energy simulation tool. One base model of commercial buildings with all required parameters shall be constructed in the software. The researcher shall implement the required

energy efficiency measures in a sequence which will lead to conservation of energy and energy saving within the system. The researcher seeks to achieve the energy saving from the current energy consumption through the proposed research which will be a great achievement for the entire community involved in energy conservation of buildings.

Researcher seeks to use energy modeling and simulation software tools to construct and develop the energy model for commercial building. The eQUEST software is a graphical user interface to DOE-2.2, whole building energy analysis tool. The software consists of a building creation wizard, an energy efficiency measure wizard, and a graphical reporting feature with a simulation engine derived from the latest version of DOE-2.2. The work shall be based on the methodology developed for the evaluation and classification of commercial buildings in compliance with the standards. The methodology shall be as follows:

1. Criteria for selection of commercial buildings: It will be based on climate zone, building's conditioned area and building owner's project requirement using benchmark as energy star portfolio manager.
2. Sampling and data collection: Convenience sampling method will be used for sampling, and questionnaire survey will be used for data collection of commercial buildings in India.
3. Buildings envelop characterization: Design report review, drawing review, technical specification review, assessment of documents and identification of materials will be used such as bill of quantity (BOQ) in designing building envelop.
4. HVAC and electrical system characterization: Identification of HVAC system and lighting system and their use.
5. Analysis using energy modeling and simulation in eQUEST-3.63b software.
6. Assessment of building energy performance; (*i*) Investigation of impact of energy efficiency measure, (*ii*) Identification of appropriate and quantifiable energy efficiency measures, and (*iii*) Implementation of identified energy efficiency measures for energy saving calculations.
7. Comparative study of energy efficiency measures among selected commercial buildings.

8. Comparative study of cost and benefits for economical evaluation of the models among selected commercial buildings.
9. Recommendations and guidelines for appropriate energy efficiency measures based on simulation results.

The management of commercial buildings shall provide plans and design reports of the building. Researcher shall use information from the plans and design reports to develop a two-dimensional footprint of the building in AutoCAD. The footprint then shall be imported into the building creation wizard of the eQUEST software and shall be used to specify the building's location, orientation and thermal zones. The researcher shall use the elevation details from the plans, design reports and detailed field notes covering the wall construction and fenestration to develop the structure of the building in the software. This information is critical because it defines the quality of the building envelope and hence the energy usage. Researcher shall perform a survey of lighting and equipment density and will use a table of standard wattages to arrive at an estimate of lighting and equipment loads. Buildings management shall provide information about typical building occupancy. The Information shall be incorporated in the occupancy, lighting and equipment schedules and the estimated internal loads into the wizard mode. HVAC system operation, available occupants' comfort level and the perception about indoor environment observed by the facility managers of a number of commercial buildings shall be studied to identify potential area for energy saving.

The subject buildings are the upcoming commercial facilities from different climate zones of India. The subject buildings will comprise of the total built up area from 1,00,000 ft^2 to 6,00,000 ft^2 or above. The buildings comprise of offices, retail and parking areas. The overall wall window ratio shall be from 9 to 52 %. A zoning plan shall be developed for each floor and will be entered into the simulation model. Each zone shall be assigned a set of properties including lighting power density, equipment power density, occupancy rate, etc. Each zone shall be also assigned physical properties of floor-to-floor height, material conductivity & fenestration area etc.

A wide range of individual energy efficiency measures such as building envelope, lower U-values for roof and walls, lower U-values for glass, energy efficient air or

water cooled chillers, VFD pumping, lower exterior and interior LPD, VSD drive exhaust fans, regenerative drive elevators, variable speed cooling tower fans shall be added to the As-Is design to optimize the performance of the As-Is design. The commercial buildings shall be modeled using the eQUEST energy analysis software. eQUEST uses the building energy simulation engine developed by US Department of Energy (DOE). The eQUEST energy modeling software allows for a graphical display of all the 3-dimensional geometry entered in the application to describe the building. As per the view shown, the building shall be modeled in detail to improve the accuracy of analysis work. The study objective shall be to evaluate energy use and the energy efficiency performance of the building.

Proposed case assumptions and data shall be based on the project architectural drawings, HVAC floor plans, BOQ and technical specifications. All other design and operating assumptions shall be based on design narratives when available, from discussions with the design team, or reasonable assumptions based on experience and industry standards. In this study all selected cases and their As-Is models shall have poor energy performance. Hence to achieve the energy saving over As Is design, researcher shall consider few energy efficiency measures (EEM) which will enable the proposed building to be approx 18% to 20% better than the As-Is model.

The following energy efficiency measures are proposed to be analysed for systematic assessment of building energy performance in the selected commercial buildings, subject to applicability of energy efficiency measures in that building:

1. EEM–01: Wall insulation (26 mm XPS insulation): 9” brick wall and 0.75” plaster on both the sides of the walls + Extruded polystyrene (XPS) insulation (26 mm). U-value of the wall is 0.123 Btu/hr. sq feet °F. The reduced U-value shall reduce the building heat gain.
2. EEM–02: Roof insulation (60 mm XPS insulation): Flat Slab Concrete 6” + Extruded polystyrene (XPS) insulation (60 mm) + 100mm brickbat coba + 1” China mosaic tiles. U-value of roof is 0.063 Btu/hr. sq feet °F. The reduced U-value shall reduce the building heat gain.
3. EEM–03: Double glazed unit (DGU) Glass: U-Value: 0.56 Btu/hr.feet^2 °K, SC= 0.29.

4. EEM–04: Energy efficient chillers: Use of chillers with coefficient of performance (COP) = 6.1. This will reduce chiller's energy consumption.
5. EEM–05: VFD on SCHWP: Secondary chilled water pumps shall be equipped with variable frequency drives (VFD). The VFD shall increase or decrease the pump speed, hence the pump power as per the load requirement.
6. EEM–06: VFD on AHU: Air Handling Units shall be equipped with variable frequency drives (VFD). The VFD shall operate the air handling unit fan meter as per load requirement.
7. EEM–07: VFD on CT fans: Cooling tower fans shall be equipped with variable frequency drives (VFD).
8. EEM–08: SAT reset: Supply air temperature shall be reset based on outside air temperature (OAT) or cooling load.
9. EEM–09: Chilled water supply temperature reset: Chilled water supply temperature shall be reset based on outside air temperature.
10. EEM–10: Car park lighting shall be designed at the reduced lighting power densities. The recommended lighting power (LPD) density shall be 0.15 W/ft^2. The lux shall be maintained around 100-150.

The Energy Efficiency Measures EEM-1, EEM-2 and EEM-3 will lead to improved building envelop parameters. These energy efficiency measures shall reduce building heat gain; hence building cooling/ heating load shall be reduced. EEM-4 to EEM-9 leads to improved HVAC system. And EEM-10 shall reduce the energy consumption due to lighting system.

Work Plan

The means of collecting information for the research includes review of relevant literature, questionnaire survey with the building owners, and review of engineering drawings. *Figure 1.1* illustrates the various components constituting in the research methodology. The research methodology is designed to comprise different phases. These phases include extensive literature review of the subject, followed by data collection of commercial buildings, analysis and assessment of building energy performance, followed by comparative study of identified EEMs for recommendations. To accomplish it there will be formulation of case studies through the process of energy modeling and simulation tool, investigating impact of various

energy efficiency measures on energy consumption shall be done and finally identifying appropriate and quantifiable energy efficiency measures to achieve energy conservation without compromising thermal comfort shall be done.

Phase- I: Extensive literature review shall be carried out to acquire in-depth understanding of the issues related to energy conservation, thermal comfort level, building envelop, HVAC and lighting system operation and energy efficiency in commercial buildings. This phase will help to build the foundation for the research work and explore potential area for energy problems that are associated with the topic in India. This exercise will further help in developing the questionnaire for data collection of proposed commercial buildings and the buildings under design phase.

Phase- II: The next step towards the investigation of the energy problem will be to acquire useful information pertaining to the building envelop characterization, electrical system characterization, lighting requirement, HVAC design etc with the help of questionnaire survey. The As-Is drawings shall be reviewed to gather information about the thermal zoning and construction systems.

Phase-III: During this phase of research the information obtained from the above two phases shall be used in the selection of model building to form real case studies. Using the acquired data for the selected buildings As Is cases shall be formulated in eQUEST energy simulation software. The results of the base case will be for the year 2010. Formulation of As-Is model shall be done for proposed energy efficiency measures. The proposed energy efficiency measures shall be investigated in the later phase.

Phase-IV: There are numerous energy efficiency measures that can be implemented to conserve electrical energy and thermal comfort, but all of them don't help to attain both goals at same time. In this phase impact of different energy efficiency measures for building envelop, HVAC and lighting system on energy conservation and thermal comfort shall be investigated. Employing those measures might reduce the energy consumption but on the other hand may or may not be able to maintain the desired thermal comfort. Such variations in energy consumption and thermal comfort with changing HVAC operation strategies shall be studied in detail under this phase. Those

energy efficiency measures shall be identified/ selected which helps to achieve thermal comfort conditions in the building at reduced consumption. The quantifiable energy efficiency measures shall be identified in this phase with the help of building energy simulation using eQUEST software.

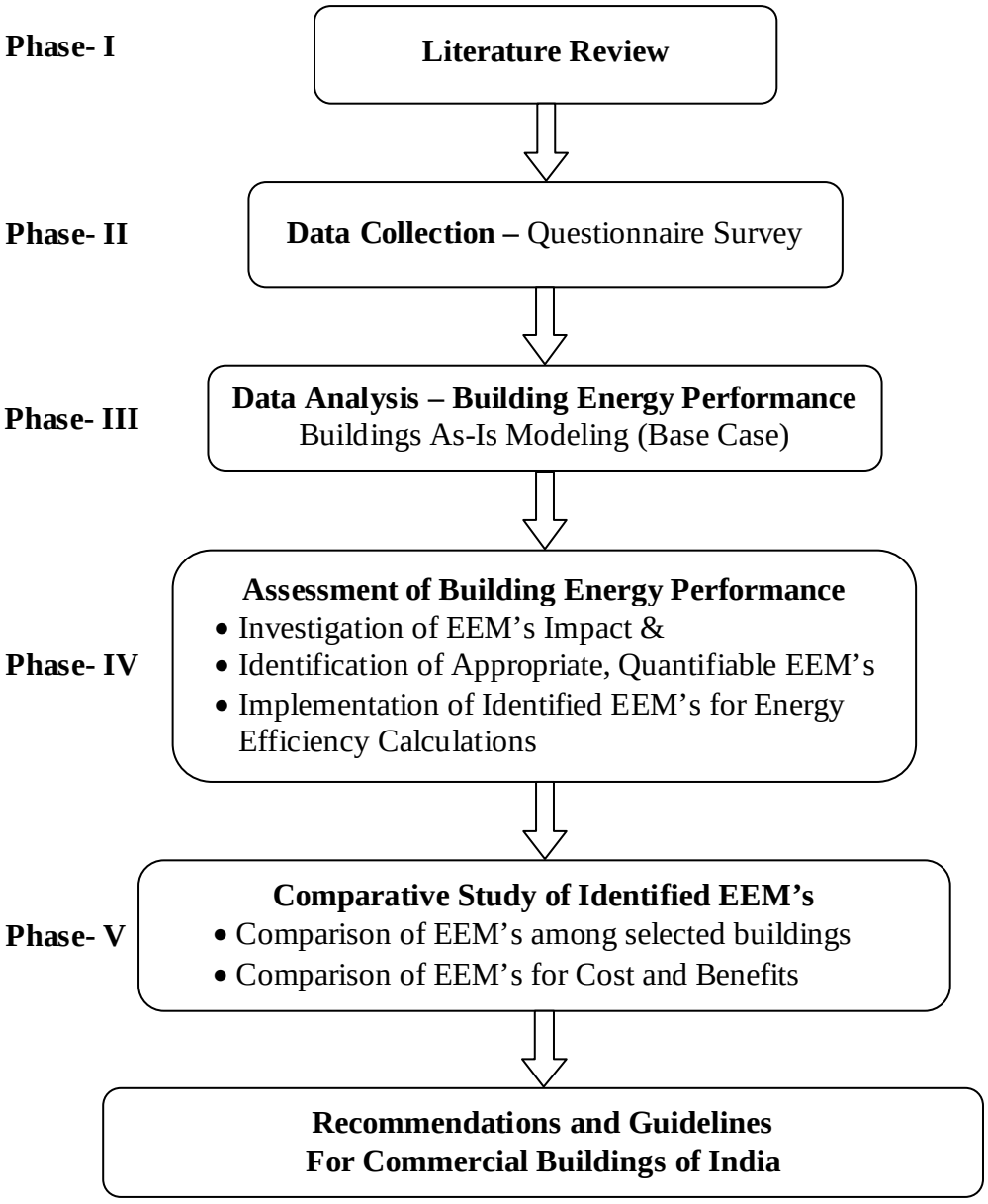
Phase- I
Literature Review
Phase- II
Data Collection – Questionnaire Survey
Phase- III
Data Analysis – Building Energy Performance
Buildings As-Is Modeling (Base Case)
Phase- IV
Assessment of Building Energy Performance
Investigation of EEM's Impact &
Identification of Appropriate, Quantifiable EEM's
Implementation of Identified EEM's for Energy Efficiency Calculations
Phase- V
Comparative Study of Identified EEM's
Comparison of EEM's among selected buildings
Comparison of EEM's for Cost and Benefits
Recommendations and Guidelines
For Commercial Buildings of India

Figure 1.1 Flowchart Showing Different Phases of the Research Methodology

Phase-V: In this phase among the energy efficiency measures identified in earlier phase shall be compared among selected commercial buildings of India. Based on the final cost benefit analysis outcome, recommendation of appropriate energy efficiency measures and guidelines shall be suggested for the commercial buildings of India.

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